Eastern Region Technical Attachment
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A CASE STUDY OF A FAST MOVING SNOWSTORM IN CENTRAL OHIO ON JANUARY 25, 1992

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1. INTRODUCTION

On January 25, 1992 a heavy snowfall event occurred over central Ohio and central West Virginia. The storm originated over the Dakotas and moved rapidly southeastward to the Ohio Valley during the afternoon and evening of January 25. The storm dropped 1 to 3 inches of snow across northern Illinois and Indiana during the morning and early afternoon. Snowfall amounts quickly increased as the storm approached western Ohio. A narrow swath of 4 to 6 inches of snow fell over central Ohio and West Virginia, with a few reports of 8 to 10 inches in the higher elevations of West Virginia.

This storm produced snowfall rates as high as 2 inches per hour that resulted in numerous traffic accidents and isolated power outages. The storm also produced 6 inches of snow at the Columbus Airport, which was the greatest 24 hour snowfall in Columbus since January of 1988. Although the snowfall may have been enhanced by convection at times, there were no reports of thunder or lightning.

The NMC heavy snow discussion indicated a 2 to 4 inch snowfall over central Ohio ending at 0000 UTC January 26. In spite of anticipated upper-level dynamical forcing, NMC expected only 2 to 4 inch amounts due to the rapid movement of the storm and limited low-level moisture.

The purpose of this study is to examine the upper level dynamics and isentropic features (including a theta-e analysis), which created an environment favorable for enhanced snowfall over the Ohio Valley, with convective snowfall over portions of central Ohio.

2. SYNOPTIC OVERVIEW

A relatively fast, northwest flow was evident over the northern Plains and Ohio Valley, with several short-waves rotating through a broad upper level trough (Figs. 1a-1c). A 100 kt, 500 mb jet was over the mid Mississippi Valley at 1200 UTC 25 January. The jet streak moved to the Tennessee Valley by 0000 UTC, which placed Ohio and West Virginia in the left front quadrant during the afternoon of January 26 (Figs. 1a-1c). Two short-waves moved rapidly south eastward out of the Great Plains and phased together over Ohio by 0000 UTC January 26.

At 0000 UTC 25 January a 1004 mb surface low was centered near Pierre, South Dakota, and a ridge of high pressure extended from the Gulf of Mexico to the Great Lakes (Fig. 2a). The low moved to Moline, Illinois by 1200 UTC, while the ridge moved eastward over the Atlantic seaboard (Fig. 2b). The low continued to move rapidly south-eastward during the next 12 hours, and was centered near Charleston, West Virginia by 0000 UTC January 26. The surface high remained over Lake Ontario during this time and weakened slightly from 1025 to 1023 mb (Figs. 2c-2d). The nearly stationary surface high was important in this case, because it maintained an overrunning surface over the Ohio Valley.

A 50-kt, 850 mb jet was positioned over the lower Ohio Valley at 1200 UTC January 25, with a strong thermal gradient also present over Indiana, Ohio, and West Virginia (Figs. 3a-3b). One would expect strong warm air advection to take place over Ohio between 1200 UTC and 0000 UTC 26 January. However, the warm air advection over Ohio was short-lived due to the rapid southeastward translation of the low. The primary region of warm air advection was east of the Appalachian Mountains by 0000 UTC January 26.

The 850 mb air that moved into Ohio between 1200 UTC and 0000 UTC appeared to lack the moisture necessary for heavy snowfall. Moisture was not impressive at 1200 UTC, as dew points over the Tennessee and lower Ohio valleys ranged from -4 to -14°C. The dew point depressions ranged from 10 to 20°C. The 850 mb chart, which is frequently used to determine if sufficient low level moisture is available, proved to be misleading in this case. Parcels seldom remain on a constant pressure surface, but they do follow constant adiabatic (or isentropic) surface. Therefore, a more accurate representation of moisture advection is achieved by analyzing an isentropic surface as opposed to a constant pressure surface.

3. ISENTROPIC ANALYSIS

The 293K isentropic surface was used for this study since it is one of the recommended surfaces for analyzing winter weather systems (Namias 1940). The 1200 UTC isentropic analysis (Fig. 4a) indicated substantial lift in the warm sector of the storm. Strong isentropic lift, indicated by cross isobaric flow, was evident from the Tennessee Valley northward to central Ohio. Parcels would be lifted as much as 150 mb as they moved along the 293K surface. Only a 15 mb lift was needed to obtain saturation over Huntington, West Virginia, while as much as a 100 mb lift was necessary over Paducah, Kentucky. Parcels were also advected on the 293K surface by a 40- to 50-knot jet, resulting in rapid lifting and saturation. Figure 4b indicates that the strong isentropic lift was short lived, diminishing by 0000 UTC January 26.

4. THETA-E ANALYSIS

Equivalent potential temperature, or theta-e, is a measure of the heat gained by a parcel from the release of all the latent heat of the water vapor within the parcel. This is accomplished by increasing the sensible temperature during a condensation process carried to the theoretical limit. Hence, a parcel must first be raised from a reference level (ie. 1000 mb) until all of its moisture is condensed out (mixing ratio = 0). Once the water vapor is removed the parcel is brought dry adiabatically down to 1000 mb.

For pseudoadiabatic ascent, the water which falls out carries a small amount of heat with it (Holton 1979). However, the amount of heat removed is considered negligible. As a result, theta-e is assumed to be conservative for both dry and moist atmospheric processes.

An adiabatic process is defined to be one in which there is no heat exchange between the parcel and the environment (Haltiner and Martin 1957). In other words there are no heat exchanges due to radiation, environmental mixing, evaporational cooling, etc.

The total derivative for theta-e can be written in the form:

$$\frac{d\theta_e}{dt} = \frac{\partial\theta_e}{\partial t} + u\frac{\partial\theta_e}{\partial x} + v\frac{\partial\theta_e}{\partial y} + w\frac{\partial\theta_e}{\partial z}.$$

Since theta-e is constant for an adiabatic process the total derivative must = 0 (adiabatic assumption).

It follows that:

$$\frac{\partial\theta_e}{\partial t} = -\left(u\frac{\partial\theta_e}{\partial x} + v\frac{\partial\theta_e}{\partial y} + w\frac{\partial\theta_e}{\partial z}\right),$$

where the righthand side of the equation is the advection term, with the local change in theta-e due purely to advection.

Quantitative assessment of theta-e advection requires calculation of the near instantaneous local change in theta-e (e.g., the rate of change based on a small time step measurement), or calculation of the advection directly. This can be a time consuming process without the aid of a computer. However, average 12-hour theta-e advection can be determined directly from the change in theta-e values on the AFOS theta-e plots generated every 12 hours. This approach was used for this study and should yield results similar to calculating the instantaneous advection at 12-hour intervals and averaging the results of each calculation.

Theta-e ridges and tight theta-e gradients are favored areas for convective development and/or enhanced snowfall (Scofield 1988); however, lifting mechanism must also be present. A high value of low level theta-e implies greater convective potential, provided fairly deep low-level moisture and fairly steep lapse rates are in place (Campbell 1991). High K indices are indicative of steep lapse rates and high low-level moisture content. Typically K indices of 10-20 are necessary for convective snowfall (Scofield 1988). In summary the following features support enhanced or convective snowfall: a theta-e ridge, positive theta-e advection, a lifting mechanism, and high K indices.

The theta-e analysis at 1200 UTC indicated a broad theta-e ridge over the mid Mississippi Valley and the western Ohio Valley (Fig 5a). The ridge amplified and sharpened as it moved to eastern Ohio by 0000 UTC (Fig. 5b).

Figures 6a and 6b show the averaged 12-hour positive 850 mb theta-e advection. By extrapolation, the southern half of Ohio and West Virginia were in the zone of maximum positive theta-e advection. Note that central Illinois and Indiana were also in the zone of maximum advection. Figures 7a and 7b show the 1200 and 0000 UTC K indices, respectively. K indices of 20 or greater were present over the southern half of Ohio and West Virginia during the afternoon and evening of January 25.

As the positive theta-e Advection field moved over the Ohio Valley, substantial vertical motion was encountered through isentropic lift, contributing to the release of convective instability. As a result, snowfall rates increased dramatically with up to 2 inches per hour observed over central Ohio between 1800 and 2200 UTC.

Positive theta-e advection and high K indices were present over Illinois and Indiana prior to 1800 UTC, but snowfall totals were only 1-3 inches since the isentropic lift was not as strong. As the storm approached western Ohio increased isentropic lift resulted in snowfall totals of 4-6 inches over Ohio. The isentropic lift diminished by 0000 UTC, and as the storm moved east of the Appalachians snowfall totals lowered to 1-3 inches (Figs. 9a-9b).

5. UPPER LEVEL DYNAMICS

Several upper level dynamic features also contributed to enhancing the upward vertical motion over the Ohio Valley. Strong positive isothermal vorticity advection (PIVA) occurred over southern Ohio and West Virginia between 1800 and 0000 UTC January 26 (Fig. 8). PIVA is an attempt to solve the Omega equation graphically by representing differential vorticity advection and thickness advection. For PIVA, the vorticity is advected by the 1000-500 mb thickness. Since the thermal wind flows parallel to the thickness contours, PIVA advects vorticity by the thermal wind. PIVA implies increasing vorticity with height, which is necessary for upward vertical motion. This is preferable to the use of PVA, which indicates increasing vorticity at only one level and not necessarily increasing vorticity with height. The strongest PIVA, and implied synoptic scale lift, occurs where vorticity contours cross thickness contours at nearly right angles (Trenberth 1978). Figure 8 indicates nearly perpendicular advection of vorticity by the thermal wind over southern Ohio and Kentucky at 18 UTC January 25.

A second feature that contributed to upward vertical motion was the jet streak that moved through the Ohio Valley between 1200 and 0000 UTC 26 January. By extrapolation, southern Ohio and West Virginia were in the left front quadrant of the jet between 1800 and 0000 UTC (Figs. 10a-10b). The upper level jet streak and associated vertical ageostrophic circulation is crucial in linking low and upper level features to the development of heavy snowfall. Heavy snow usually develops in the indirect transverse circulation within the diffluent exit region of the jet streak (Kocin and Uccellini 1987). In the exit region, stronger winds enter a region of lighter winds, the pressure gradient force decreases and the Coriolis force has not decreased enough to balance the now weaker pressure gradient force. In order to regain geostrophic balance, the excess Coriolis force must become ageostrophic. This forces an indirect transverse circulation with rising motion in the cyclonic left front quadrant and sinking motion in the anticyclonic right front quadrant. This is termed indirect because cold air is now rising and warm air is sinking. The 50-knot 850 mb and isentropic jet maxima over the lower Ohio Valley appear to be a reflection of the indirect circulation enhancement.

6. CONCLUSION

Isentropic analysis is a powerful meteorological tool. With increased computer technology, it is now possible to generate isentropic fields from model forecast data. These analyses should be incorporated by the forecaster in the field. For the case presented in this paper, isentropic and theta-e analyses revealed the potential for enhanced upward vertical motion over central Ohio and West Virginia. Increased moisture flow into the storm, as well as increased destabilization associated with positive theta-e advection were also clearly shown.

As the positive theta-e advection field moved into the Ohio Valley a significant increase in vertical motion was encountered due to increased isentropic lift and strong upper level dynamics. As a result, the convective instability was increased and snowfall rates rose dramatically with rates as high as 2 inches per hour observed over central Ohio and central West Virginia. Snowfall totals increased from 1 to 3 inches over the western Ohio Valley to 4 to 6 inches over central Ohio and West Virginia. As the storm moved east of the Appalachian Mountains, the isentropic lift diminished and snowfall totals lowered to 1 to 3 inch amounts.

Finally, although theta-e is a useful meteorological tool, additional research is essential in order to obtain quantitative results from theta-e analyses.

7. ACKNOWLEDGEMENTS

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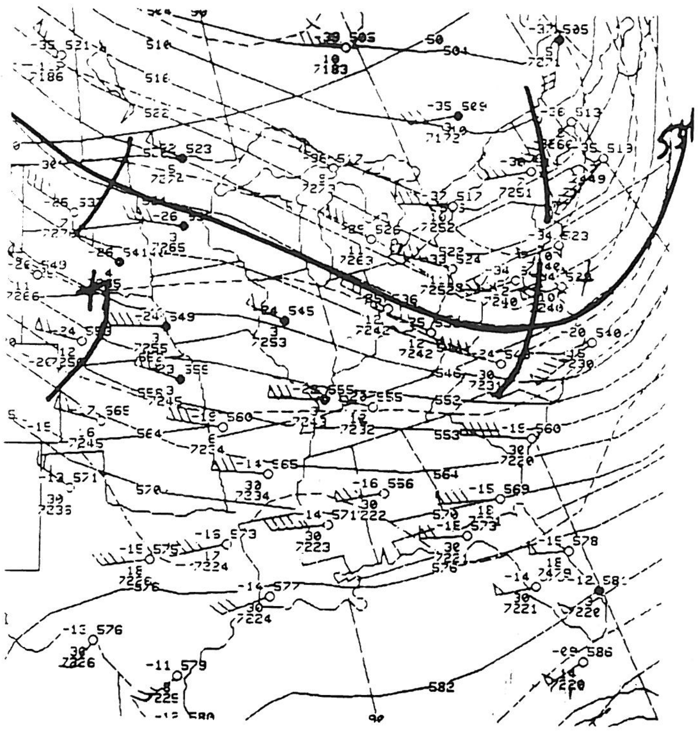

FIGURE 1a: 500 mb analysis for 00 UTC January 25th. X's are NGM vorticity maxima and thick solid lines are analyzed short wave troughs.

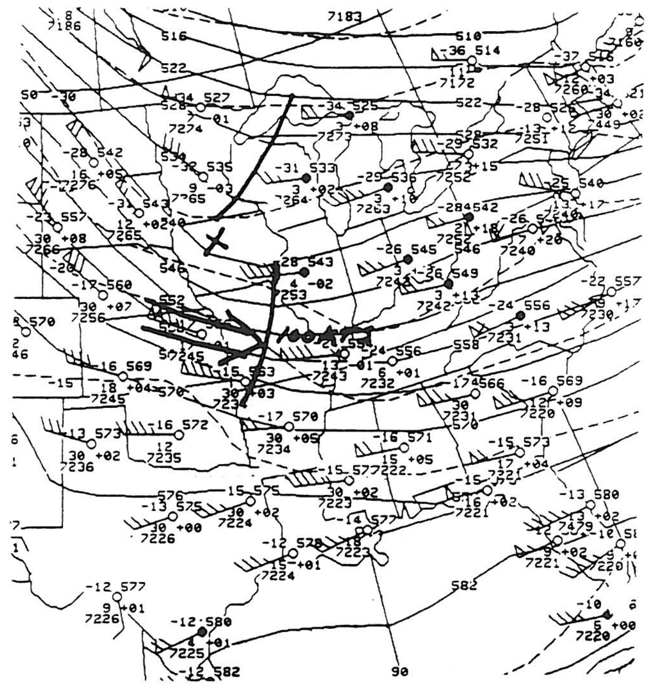

Figure 1b: 500 mb analysis for 12 UTC January 25th. X's are NGM vorticity maxima and thick solid lines are analyzed short wave troughs.

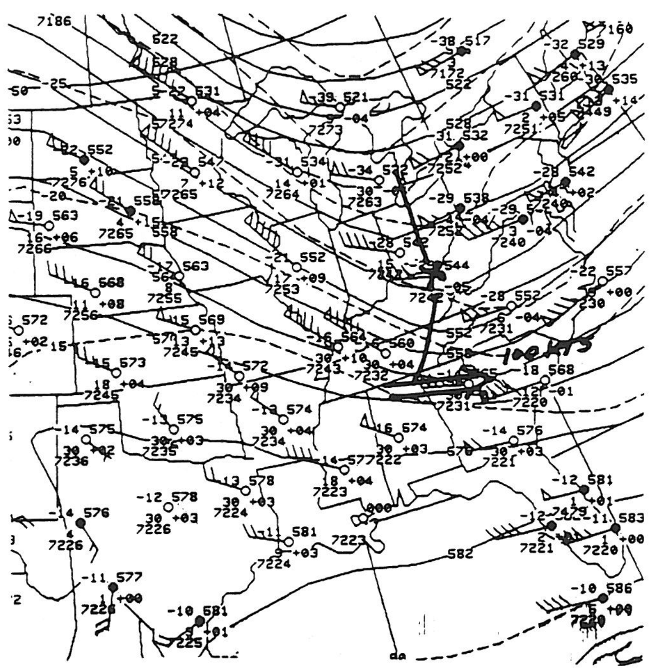

FIGURE 1c: 500 mb analysis for 00 UTC January 26th. X's are NGM vorticity maxima and thick solid lines are analyzed short wave troughs.

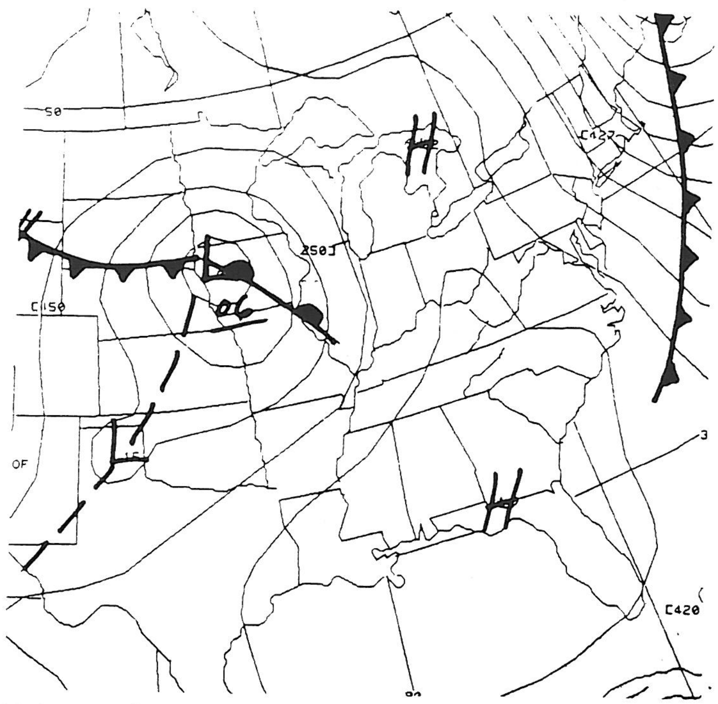

FIGURE 2a: Surface analysis for 06 UTC January 25th.

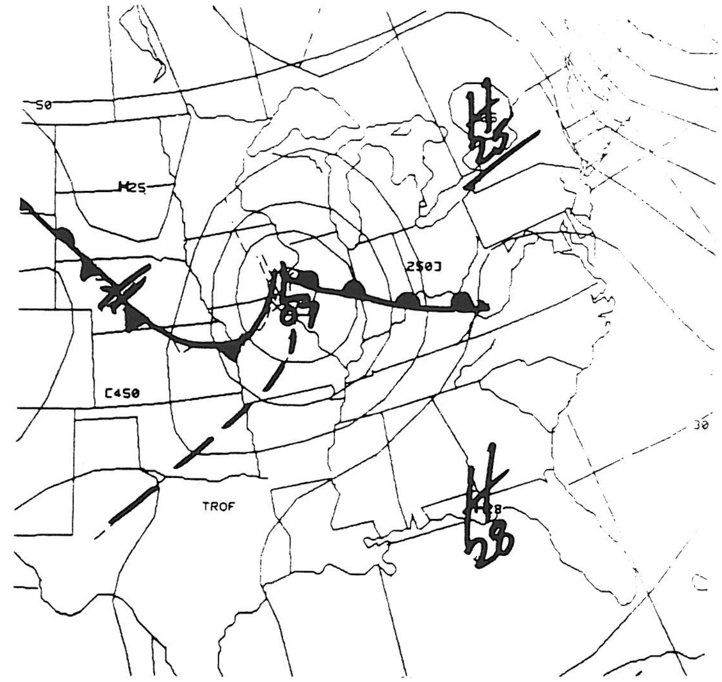

FIGURE 2b: Surface analysis for 12 UTC January 25th.

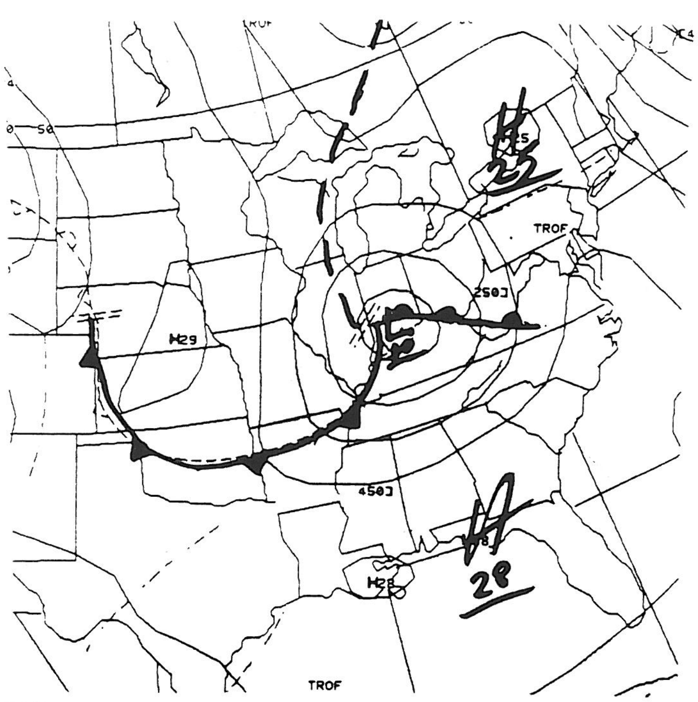

FIGURE 2c: Surface analysis for 18 UTC January 25th.

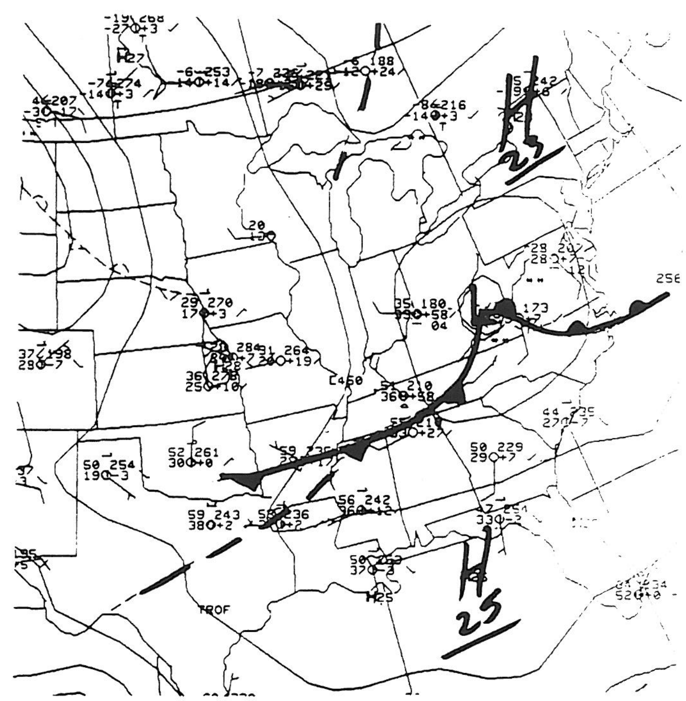

FIGURE 2d: Surface analysis for 00 UTC January 26th.

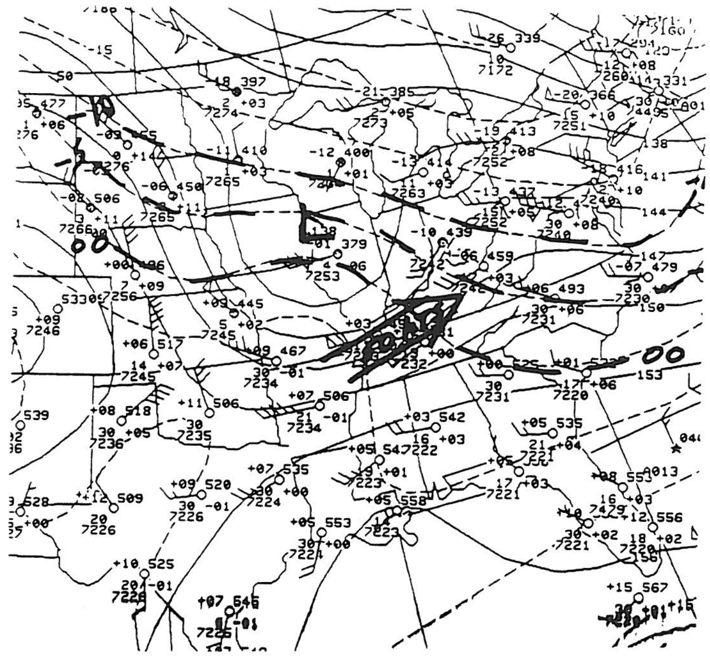

FIGURE 3a: 850 mb analysis for 12 UTC January 25th.

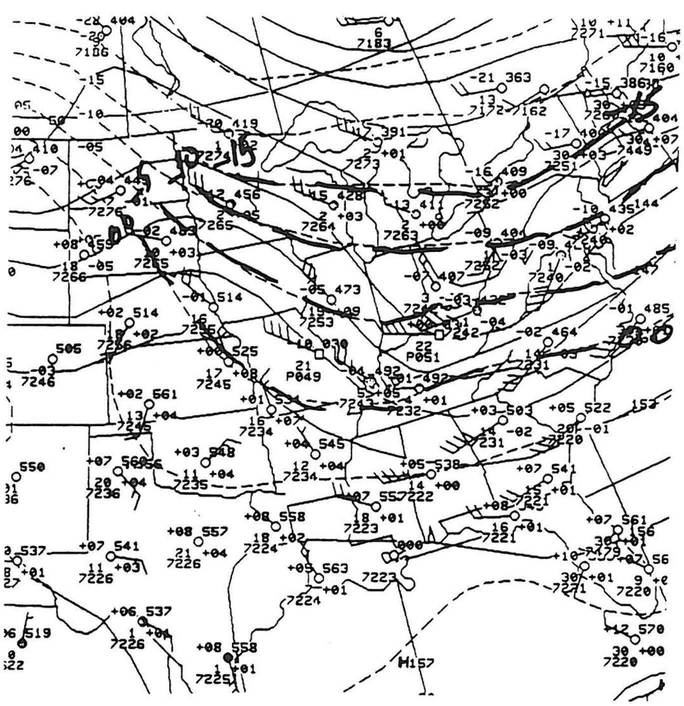

FIGURE 3b: 850 mb analysis for 00 UTC January 26th.

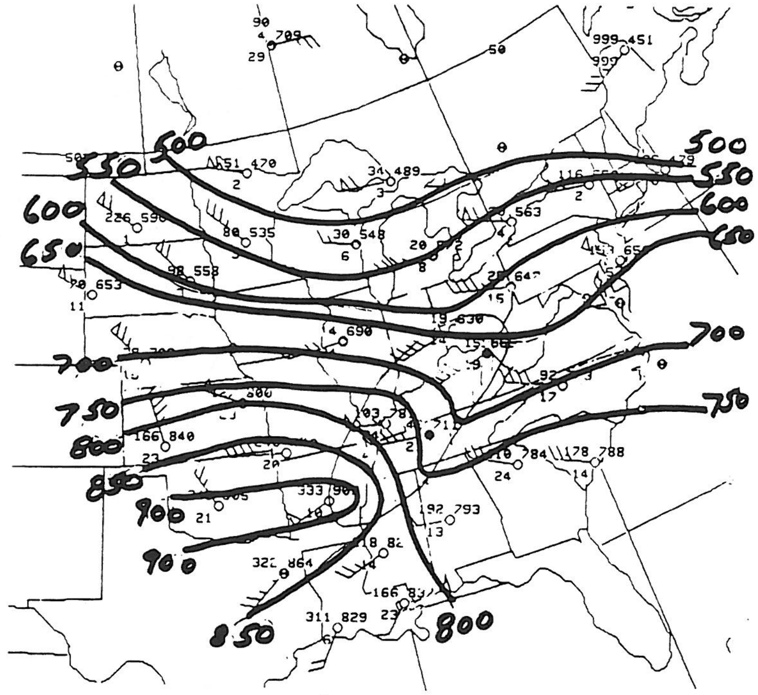

FIGURE 4a: Isentropic analysis for 12 UTC January 25th. (Analysis for 293K Surface.)

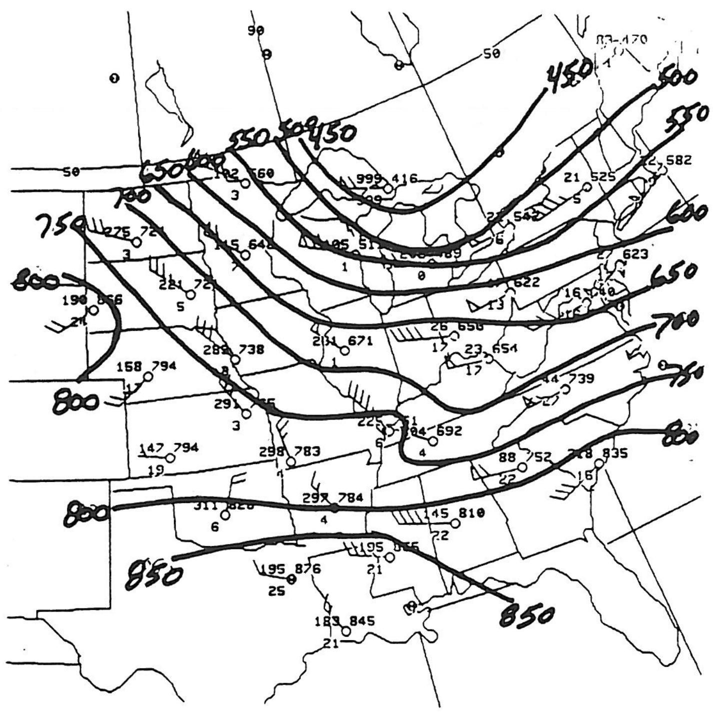

FIGURE 4b: Isentropic analysis for 00 UTC January 26th.

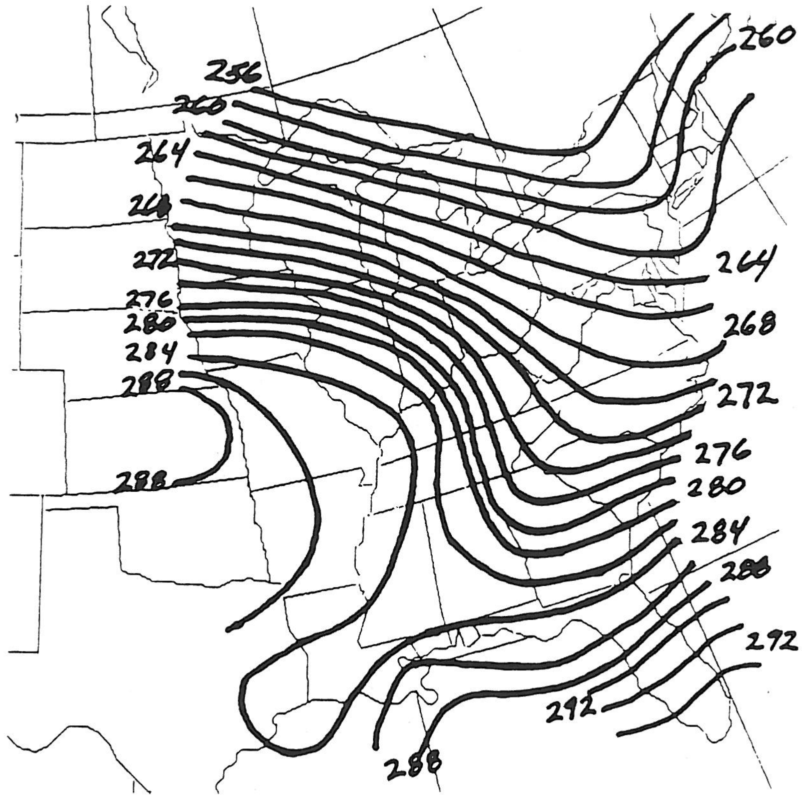

FIGURE 5a: 850 mb theta-e analysis for 1200 UTC January 25th.

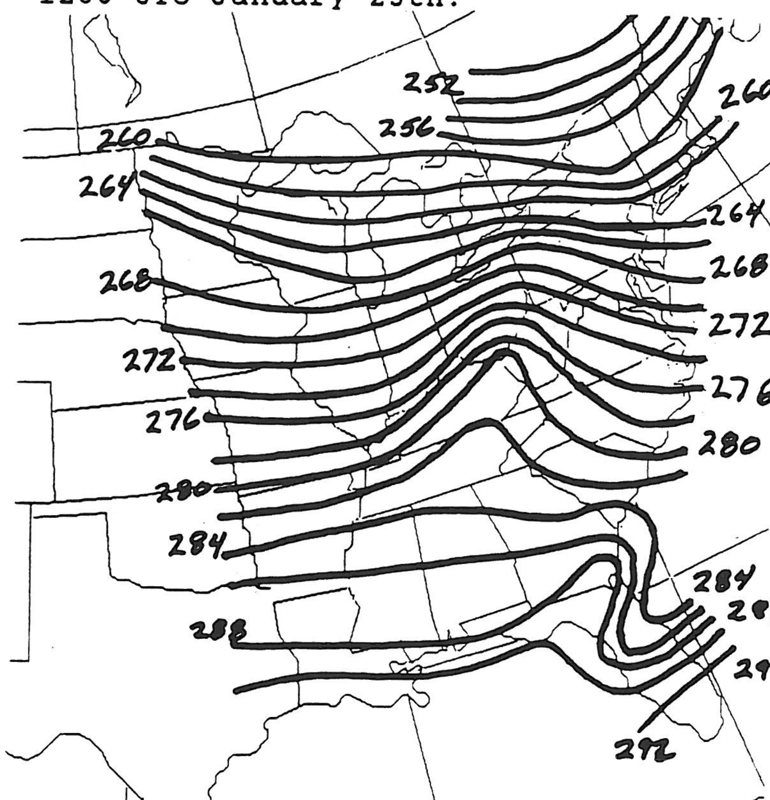

FIGURE 5b: 850 mb theta-e analysis for 00 UTC January 26th.

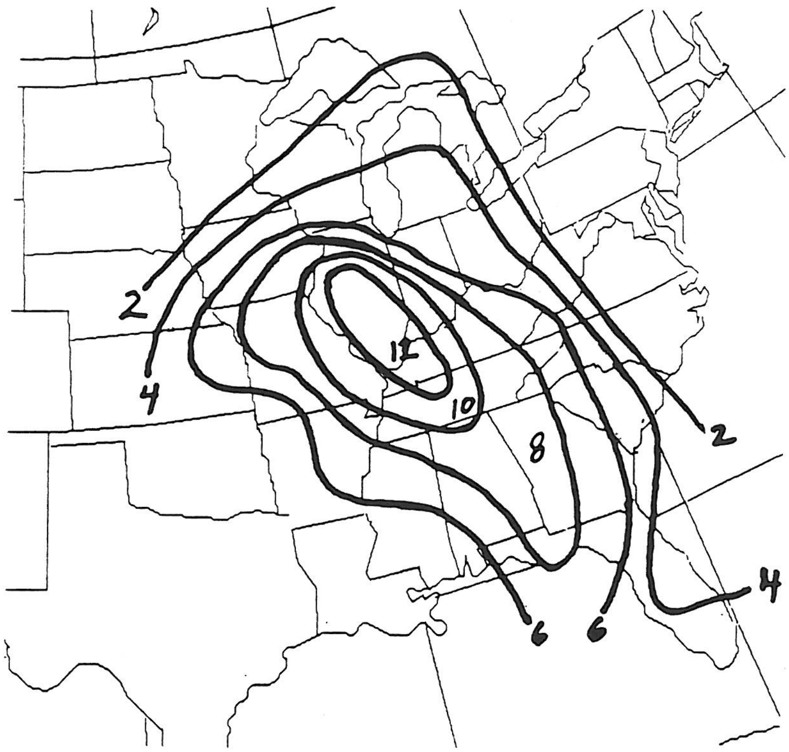

FIGURE 6a: 850 mb average theta-e advection for 00-12 UTC January 25th ($^{0}K/12hr$).

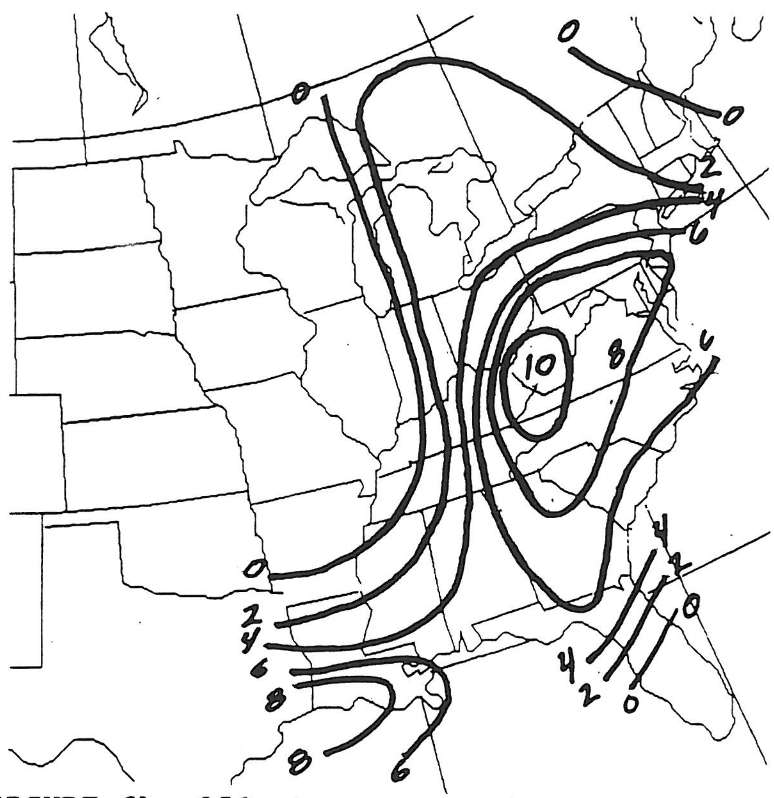

FIGURE 6b: 850 mb average theta-e advection for 12-00 UTC January 26th ($^{0}K/12hr$).

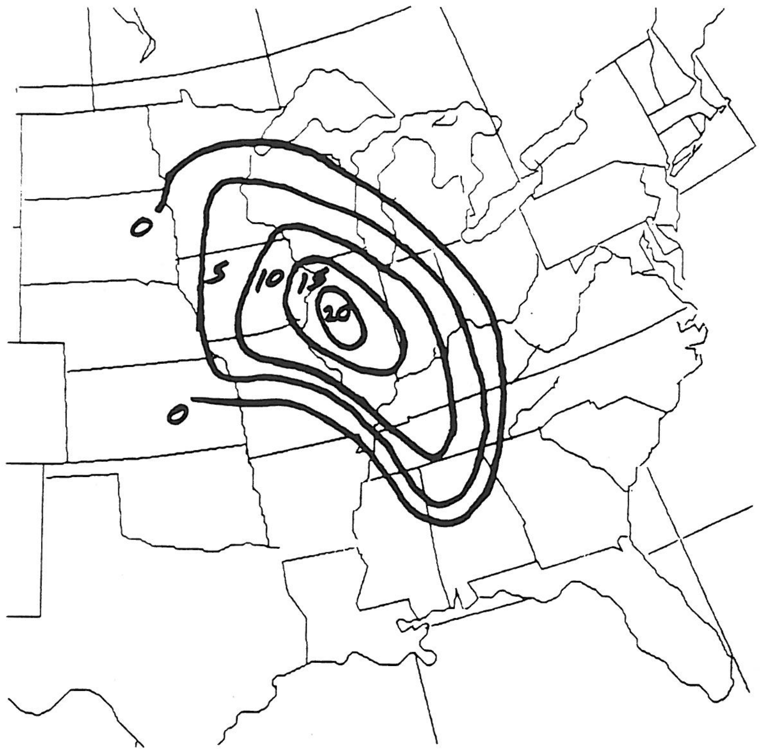

FIGURE 7a: K index for 12 UTC
January 25th.

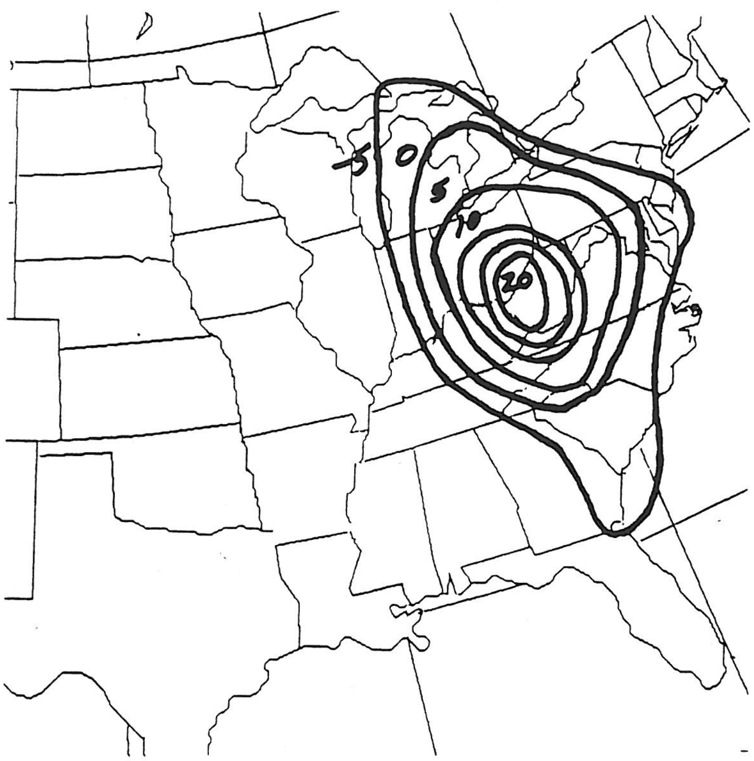

FIGURE 7b: K index for 00 UTC
January 26th.

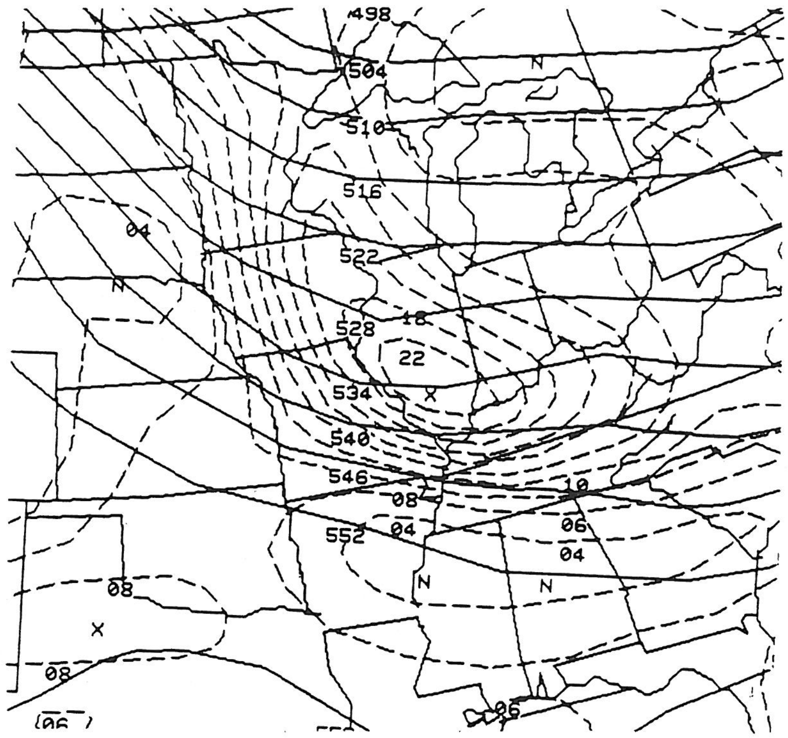

FIGURE 8: 1000-500 mb thickness (solid contours) and vorticity (dashed lines) for 18 UTC January 25th.

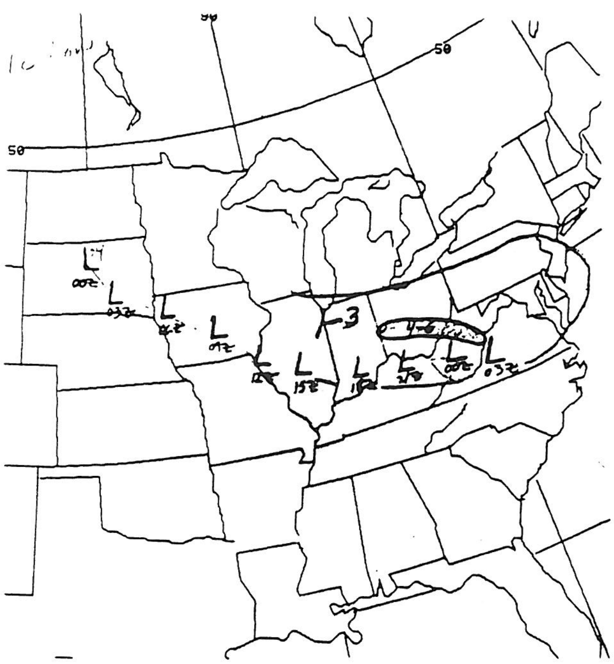

FIGURE 9a: Total storm snowfall and surface low positions.

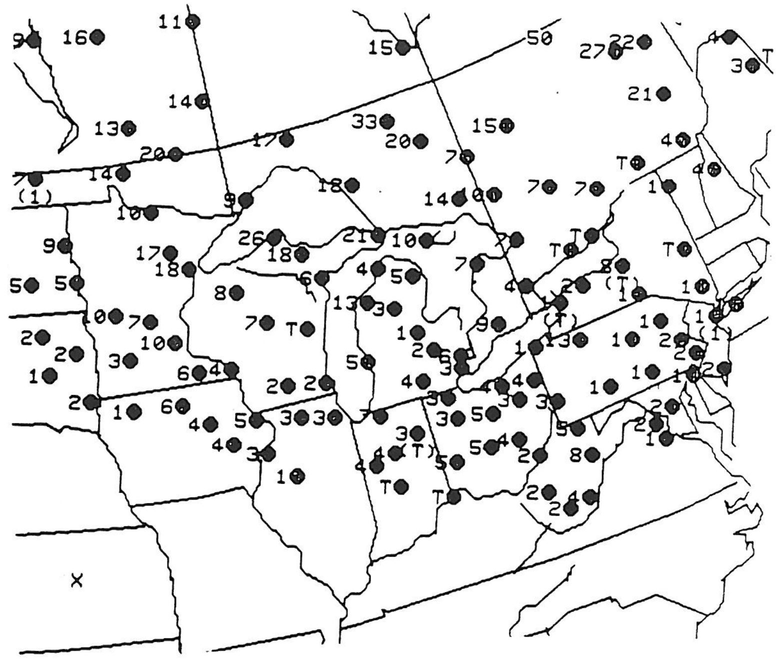

FIGURE 9b: Observed snow cover at 12 UTC January 26th.

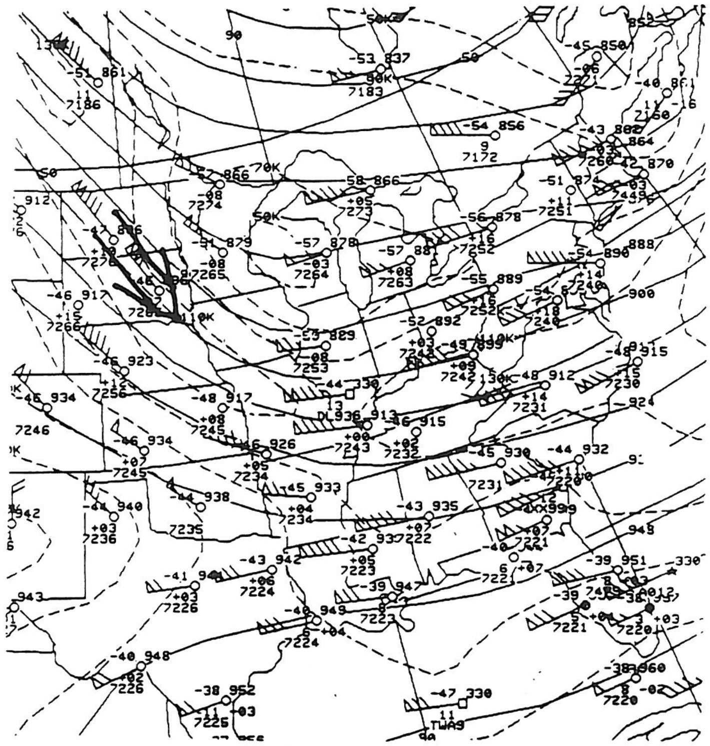

FIGURE 10a: 300 mb analysis for 12 UTC January 25th.

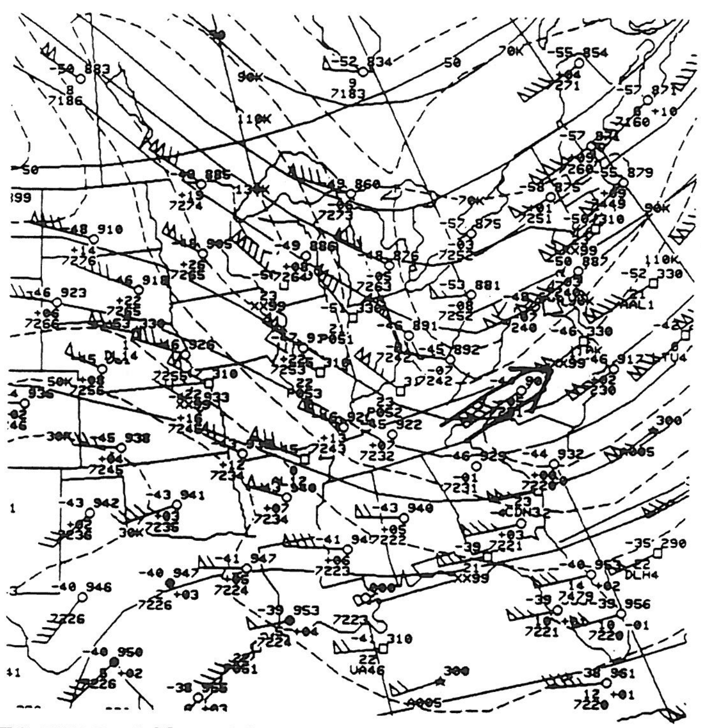

FIGURE 10b: 300 mb analysis for 00 UTC January 26th.